



Scientific Ballooning Technologies Workshop

Balloon Thermal Model Design Parameters and Sensitivities

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May 16, 2019

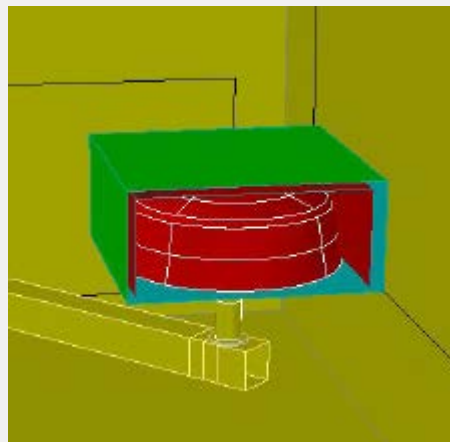
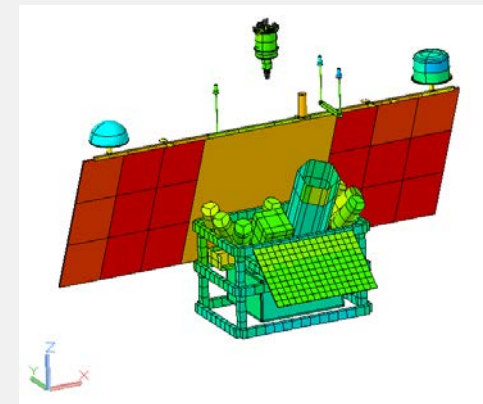
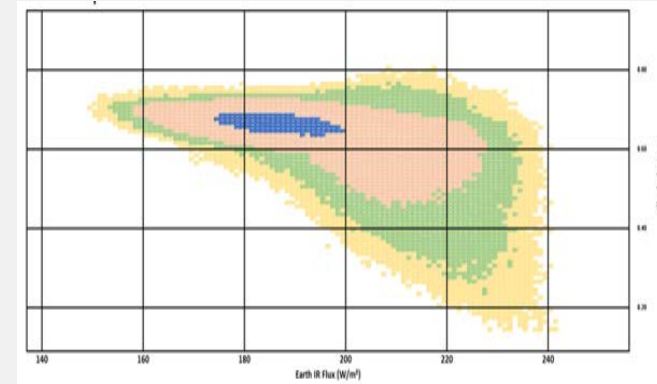


Balloon Thermal Model Design Parameters and Sensitivities

Outline



- Recent process improvements regarding environmental parameters
 - Spreadsheet tool
 - Conservative modeling approach
- Recent process improvements w.r.t. convection
 - Comparison of PMC-Turbo solar array temperatures
 - Iridium Pilot antenna (and other) back-correlation efforts
- Future Plans for thermal models
 - Ascent
 - Convection



- As many as three regions of a balloon experiment are analyzed, each typically with its own model.
 - Gondola and components
 - Flight train
 - Apex Plate
- Three mission phases
 - Ground
 - Ascent
 - Float
- Three methods of heat flow
 - Conduction – relatively simple
 - $Q = kA(\Delta T)/L$ or $Q = h^*A(\Delta T)$
 - Radiation – harder
 - $Q = \sigma \epsilon A F (T_1^4 - T_2^4)$
 - Convection – harder still
 - $Q = hA(\Delta T)$; the proper “h” is highly situation-dependent
 - Often neglected; expanded effort is planned

Balloon Thermal Model Design Parameters and Sensitivities

Environmental Parameters (Radiation)



- Radiation heat transfer in a thermal model refers to three processes:
 - Heat absorbed by the balloon model's exterior surfaces from:
 - Direct solar (UV)
 - Indirect solar, mainly albedo (UV)
 - Earth emission (IR)
 - Heat radiated by external model surfaces to deep space (IR)
 - Radiation between surfaces in a model (IR)
 - Often minor
- Two key parameters for each surface treatment are the coefficients of radiation heat transfer, α (solar absorptance) and ε (infrared emittance)
 - ε is the coefficient of IR radiation heat transfer, including *absorbed* IR radiation
 - α and ε are always greater than zero, and no more than unity.

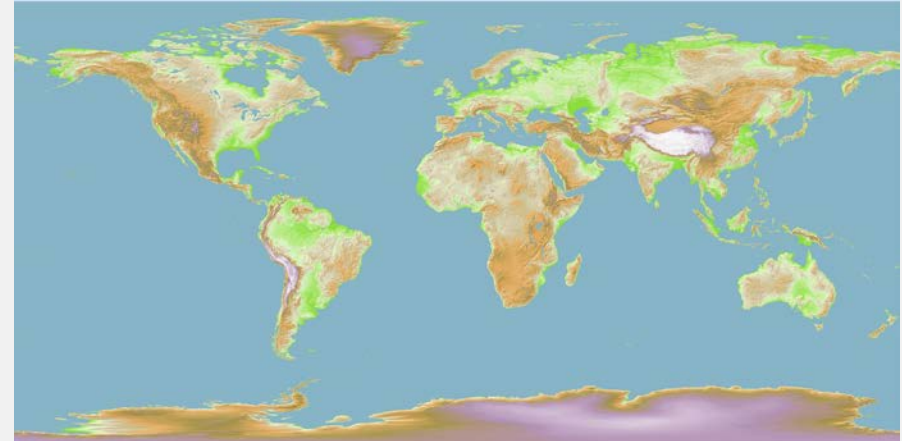
- NASA's CERES database of Top-of-Atmosphere (TOA) properties enables thermal modelers to determine appropriate, conservative albedo factor and Earth IR flux values for specific balloon missions.
 - The database contains specific values for each calendar day over decades.
 - The data is discretized by 2.5° latitude and longitude increments ("bins") over most of the Earth.
- We have recently converted an existing MATLAB-based TOA search tool to Excel, using Visual Basic logic to scan the database.
 - Close-up review of the data
 - Enables quick turnaround of "what if" questions

Red = ice or clouds, high (~ 0.6) albedo factor

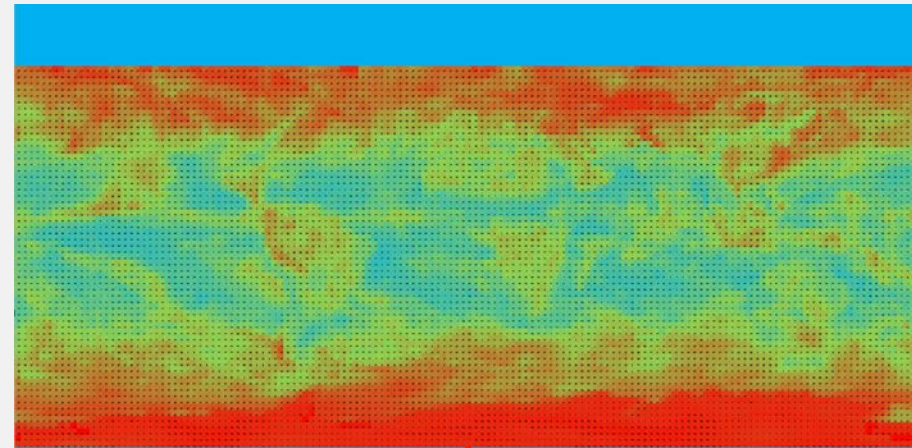
Green = land, moderate (~ 0.4) albedo factor

Light blue = ocean water, low (~ 0.15) albedo factor

N.B. albedo factors vary with weather and time of year also!



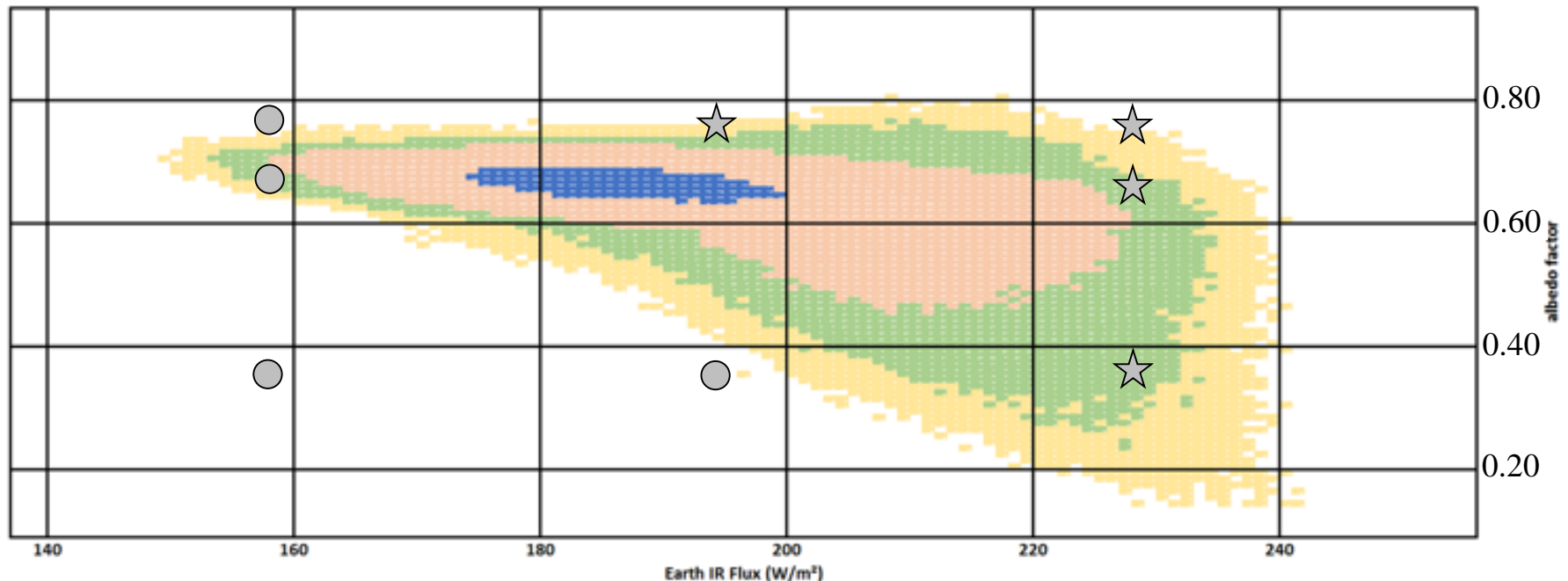
World map with TOA albedo factor data mapped onto it



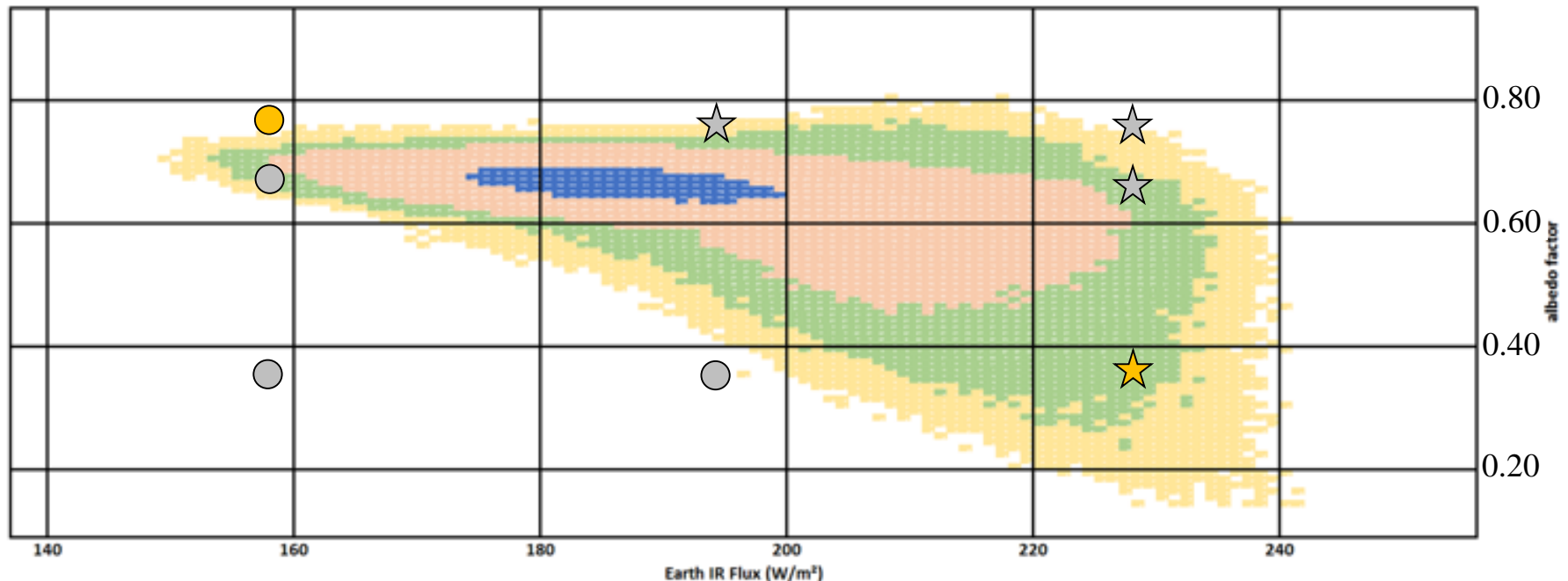
- User inputs to the search tool include:
 - The possible range of flight dates
 - The considered range of possible latitude (at float)
 - Longitude range (can be “all”)
- The search tool narrows the TOA data from the 50 million-plus values in the database to those relevant to the search inputs.
- Probabilistic results are assembled in tables like those to the right for the GUSTO mission.
 - 98% data is highlighted, but the correct percentage of data to consider varies with the program’s risk appetite.
 - 98% is essentially a position on a “knob” we can “turn.”

	ocean case	ice case	all GUSTO
	12/10-3/24	12/10-3/24	12/10-3/24
	50 to 60°S	75 to 90°S	50 to 90°S
99% of albedo data is ≤	0.67	0.75	0.74
98% of albedo data is ≤	0.65	0.74	0.73
95% of albedo data is ≤	0.61	0.72	0.71
90% of albedo data is ≤	0.58	0.71	0.69
84% of albedo data is ≤	0.55	0.7	0.68
67% of albedo data is ≤	0.48	0.68	0.65
50% of albedo data is ≤	0.42	0.66	0.62
51% of albedo data is ≥	0.42	0.66	0.62
67% of albedo data is ≥	0.35	0.65	0.51
84% of albedo data is ≥	0.26	0.63	0.39
90% of albedo data is ≥	0.22	0.62	0.33
95% of albedo data is ≥	0.18	0.61	0.26
98% of albedo data is ≥	0.15	0.58	0.2
99% of albedo data is ≥	0.13	0.5	0.17
99% of Earth IR flux data is ≤	247	221	240
98% of Earth IR flux data is ≤	243	214	236
95% of Earth IR flux data is ≤	237	205	229
90% of Earth IR flux data is ≤	233	199	224
84% of Earth IR flux data is ≤	229	194	219
67% of Earth IR flux data is ≤	222	186	209
51% of Earth IR flux data is ≤	216	179	199
50% of Earth IR flux data is ≥	216	179	198
67% of Earth IR flux data is ≥	210	168	187
84% of Earth IR flux data is ≥	203	152	172
90% of Earth IR flux data is ≥	199	145	161
95% of Earth IR flux data is ≥	193	139	150
98% of Earth IR flux data is ≥	186	132	140
99% of Earth IR flux data is ≥	181	128	134

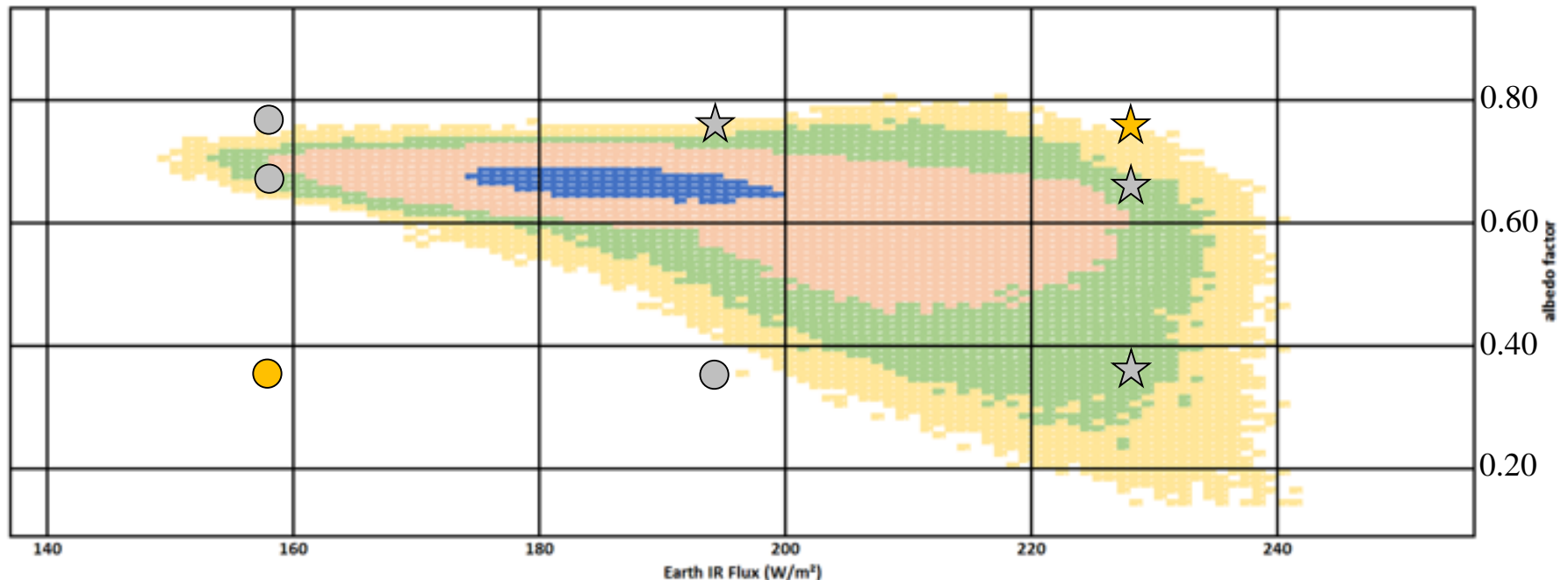
- The new Excel tool can plot a design mission's most likely albedo factor and earth IR flux data values in a color density grid.
- Each circle or star below represents one of four possible modeling approaches for a given design case set.
 - Circles represent cold-biased analysis cases.
 - Stars represent hot-biased analysis cases.



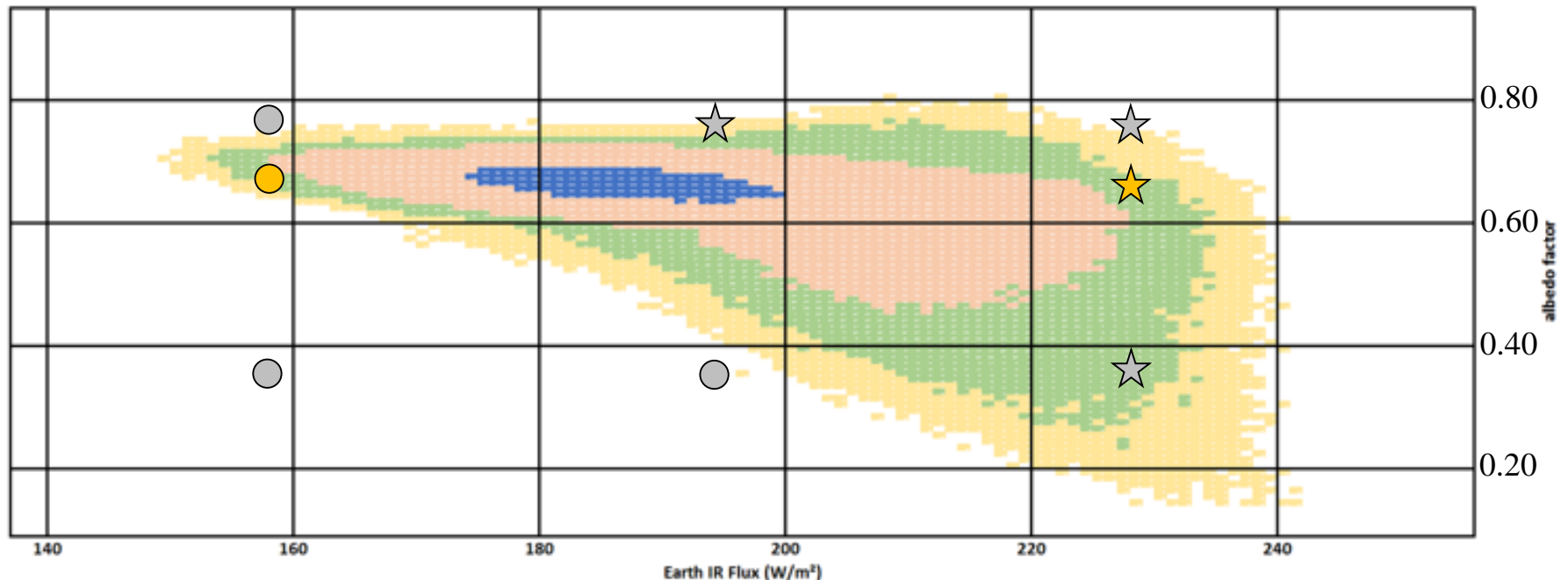
- Previous practice was to vary the two parameters inversely.
 - A low-biased albedo factor and high-biased Earth IR flux value in one case (hot)
 - A low-biased Earth IR flux value and low-biased albedo factor in the other case (cold)
- This approach employs the fact that the two parameters in reality tend to vary inversely.
- Current practice does not use this method, to achieve adequate conservatism.



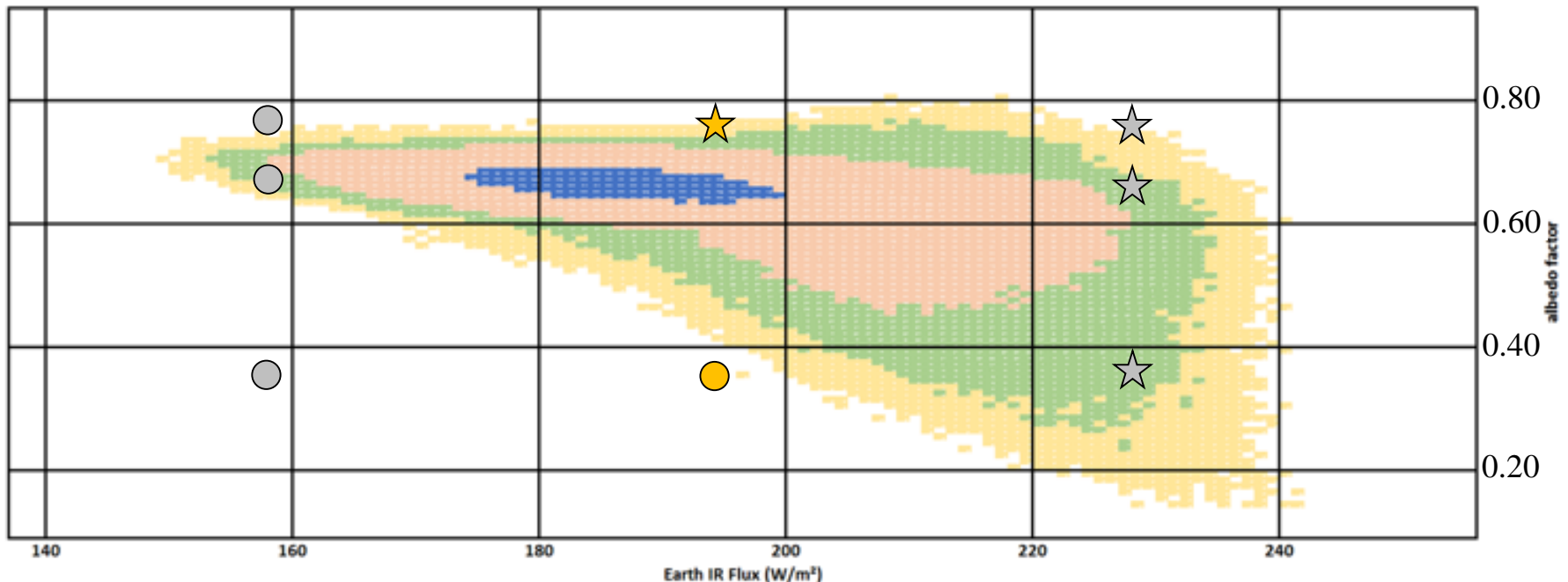
- A more conservative approach would be to select design parameter values varied in tandem.
 - This is not realistic; at least one of the design points will be far removed from the cloud of likely possibilities and produce unreasonably severe temperature (and perhaps heater power) predictions.
 - This approach is not used for balloon thermal modeling.



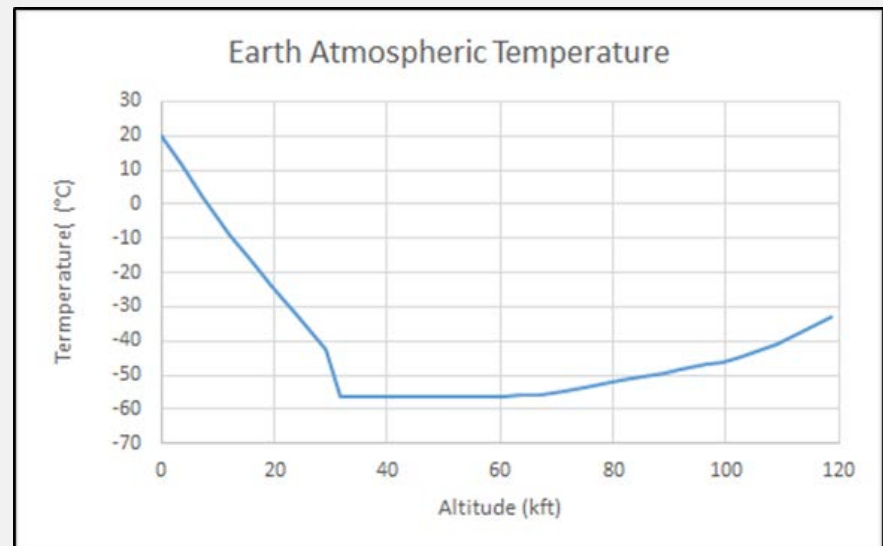
- A more realistic, yet conservative approach is as follows.
 - For the cold case: A low-biased Earth IR flux value and median albedo factor
 - For the hot case: A high-biased Earth IR flux value and median albedo factor
- Model temperatures are typically much more sensitive to the Earth IR flux value.
- No parameter is biased inversely with the design case this way, and the data modeled is inside the extreme ranges of the data “cloud.”



- An alternate approach is used in special circumstances to check the sensitivity to albedo.
 - For the cold case: A low-biased *albedo factor* and median Earth IR flux value
 - For the hot case: A high-biased albedo factor and median Earth IR flux value
- This approach is used occasionally, as test cases, during the design cycle to verify albedo sensitivity is minimal.
- An external, high- α , temperature-sensitive component might respond to this approach with an extreme (and genuine) temperature prediction, but for the vast majority of components this approach is benign.



- Convection effects on a balloon thermal model are complex.
 - The main equation is $Q = hA(\Delta T)$; with h as the “film coefficient” or “convection coefficient”.
 - The convection coefficient varies with wind speed
 - Different correlations for laminar or turbulent flow
 - At near zero velocity, natural vs. forced convection – different h relationships
 - Laminar flow and forced convection is the most relevant situation
 - Fluid property variations add complexity.
 - Conductivity, density, and viscosity vary with temperature and altitude.
 - Temperature varies with altitude (see the 1976 Standard Atmosphere below).
 - Other sources of variation exist.
 - Observations as low as -85°C
 - Standard tropopause: -56°C
 - Direction of wind speed matters.
 - Characteristic length
 - Air pressure matters.
 - ~ 0.1 atm at tropopause
 - ~ 0.01 atm at float



- Because convection heat transfer coefficients are themselves functions of temperature, convection heat transfer is thus nonlinear.
 - Coefficients vary from surface to surface within a model, and also vary with time.
 - Heat transfer coefficients are derived mostly from empirically-derived relationships.
 - These relationships use dimensionless parameters e.g. Re, Pr, and Nu.
- Some notes from a CSBF intern's work are to the right, showing the complex variability of the convection coefficient determination.
- Textbook Nusselt number correlations like these all have an applicable range of conditions or stipulations e.g. Reynolds number range, laminar flow, horizontal plate, etc.

Ivan Huerta
10/19/17
Test Model Report

Nusselt Numbers

$$Nu_1 := .0296 \cdot (Re_1)^{\frac{4}{5}} \cdot (Pr)^{\frac{1}{3}} = 828.701 \quad Nu_3 := .0296 \cdot (Re_3)^{\frac{4}{5}} \cdot (Pr)^{\frac{1}{3}} = 2.464 \cdot 10^3$$
$$Nu_2 := .683 \cdot Re_2^{.466} \cdot Pr^{\frac{1}{3}} = 70.084$$

Heat Transfer Coefficients

$$h_1 := \frac{Nu_1 \cdot k}{l_b} = 33.607 \frac{kg}{s^3 \cdot K}$$

$$h_2 := \frac{Nu_2 \cdot k}{d_c} = 29.918 \frac{kg}{s^3 \cdot K}$$

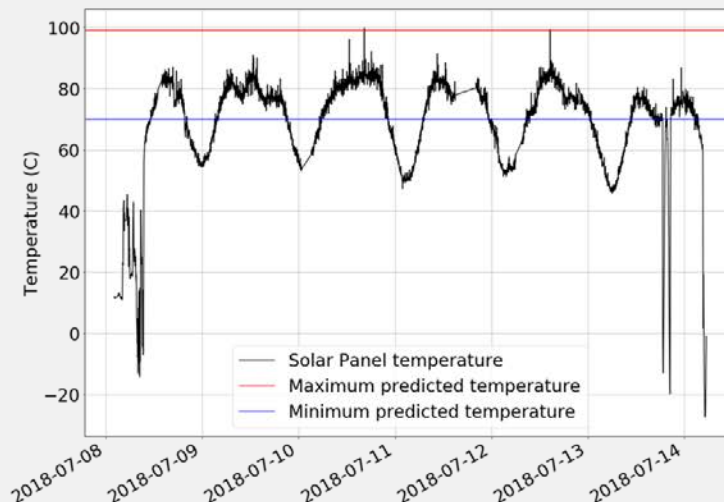
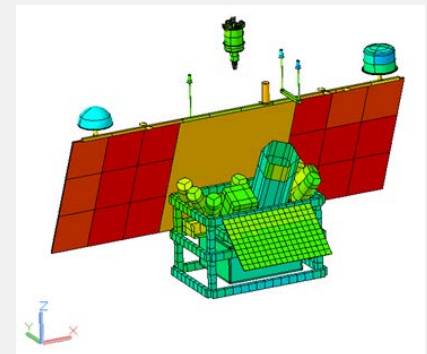
$$h_3 := \frac{Nu_3 \cdot k}{l_{bo}} = 10.237 \frac{kg}{s^3 \cdot K}$$

- Referring to Christopher Geach's presentation, the PMC-Turbo solar array flight temperatures were somewhat colder than predicted in a convection-free model.
- Simple spreadsheet estimates of convection (at float) for a hypothetical unit solar array area calculated a temperature difference of 13 degrees Celsius.

zero convection	realistic convection	extreme convection	
1	1	1	in ² , panel area
0.9	0.9	0.9	panel α
0.8	0.8	0.8	panel ϵ
0.9	0.9	0.9	W/in ² , solar constant
350	337	302.5	K, panel T (user input)
243	243	243	K, air T
3	3	3	K, space T
268	268	268	K, experiment T
1.5	1.5	1.5	view factor to space, 2= perfect 2-sided view
0.5	0.5	0.5	view factor to experiment
1.2	1.2	1.2	in ² , radk to space
0.4	0.4	0.4	in ² , radk to experiment
3.66E-11	3.66E-11	3.66E-11	W/in ² -K ⁴ , S-B constant
0	2	10	W/m ² -K, user-input convection coefficient
0	0.001	0.006	W/in ² -K, assumed convection coefficient
0.80	0.80	0.80	W, solar input
0.66	0.57	0.37	W, radiation to space
0.14	0.11	0.05	W, radiation to experiment
0.00	0.12	0.38	W, convection to air
0.00	0.00	0.00	W, heat balance, net input, ideally zero

- Other factors may have played a role in the discrepancy.

CSBF PMC-Turbo Model

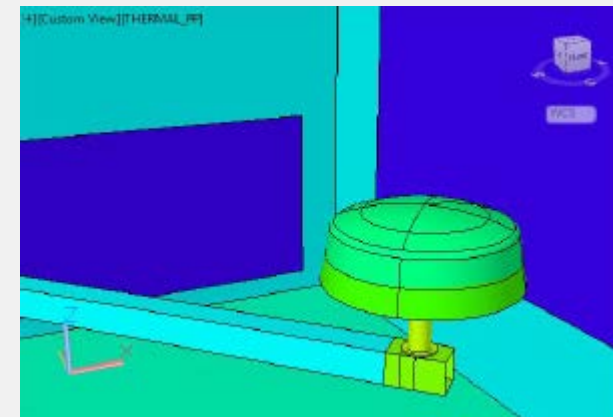


- An intern research project is in work to assess the effect of convection on a SIP heat shield during a typical mission.
- Our intern developed a Thermal Desktop-based set of symbols, useful for automating convection calculations in future models.
- Results of the heat shield test model are preliminary at this point.
 - Early returns show ascent phase convection effects on the order of 10°C on the SIP heat shield.
 - At float, convection effects are much reduced, on the order of 2°C.
 - SIP components, residing inside a heat shield, are affected less, especially if well-isolated from the SIP shield.
- A 13°C difference for a solar array at float seems large...but may be consistent with the heat shield finding. An illuminated solar array has a large ΔT to the ambient air, even at float.

Convection



- An Iridium Pilot antenna has been the subject of recent testing and analysis, partially for the purpose of assessing convection.
- Temperature data has been collected for the antenna operating in different conditions.
 - Palestine launch pad
 - Internal CSBF building
 - Several BEMCO test chamber conditions
 - With and without foam insulation
 - With and without active chamber fans
 - With and without active LN2 panels
 - At ambient or float air pressure
 - At different test control heater settings
- CSBF interns have correlated a model to the above data collected in different environments and configurations.
 - Convection calculations were part of the task.
- The next step is to adjust the back-correlated model to a future flight model.
 - A different set of convection calculations is required.



- The following actions are planned for future CSBF thermal models.
- Convection will be modeled in specific circumstances.
 - External components that can't survive tropopause conditions are a key focus.
 - Large, external, and solar-illuminated surfaces like solar arrays and radiator panels are good places to start.
 - They tend to have the highest “h” values, which lend themselves to conservative hand calculations for other surfaces/components.
 - External components that can't survive tropopause conditions are a key focus.
 - We may consider convection only in cold-biased cases, and perhaps only during ascent.
- Balloon film will be modeled at air temperature, even at float.
- Automation is a goal; creating convection couplings manually is time-consuming but can complicate proceeding model adjustments.
- We will consider modeling the ascent phase separately.
 - Separate, i.e. less extreme, TOA values will apply.
- Ongoing research objectives include:
 - CERES and other NASA data – update TOA database and search tool as needed
 - New data
 - Context of existing data
 - Similar databases, especially covering at intermediate altitudes
 - Conservative and realistic